SDO Flight Software Systems Engineering

Manuel Maldonado

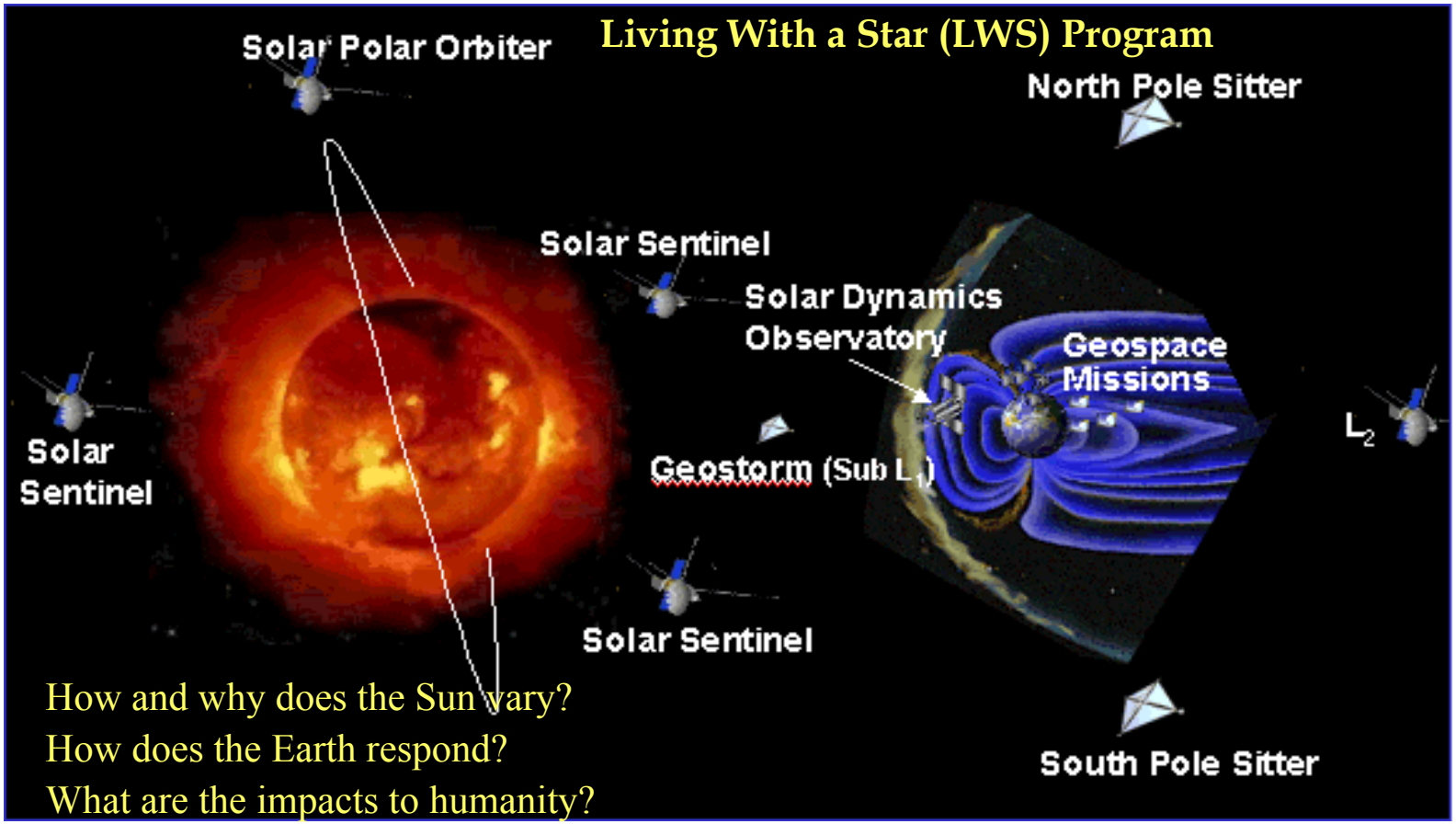
SDO Software Systems Engineer

Agenda

- Introduction to the SDO Mission
- Software Systems Engineering Role
- Spacecraft Bus FSW
- Instruments FSW

Living With a Star Science Objectives

- **SDO is the 1st mission under the Living With a Star (LWS) Program.**
  - LWS is part of NASA's Sun-Earth Connection (SEC) theme (Space Science Enterprise/Code S).
  - LWS utilizes a systems approach (inter-related missions) to develop the scientific understanding to address those aspects of the connected Sun-Earth system that directly affect life and society.
  - Primary goal of the SDO mission is to understand, driving towards a predictive capability, the nature and source of the solar variations that affect life and society by determining.



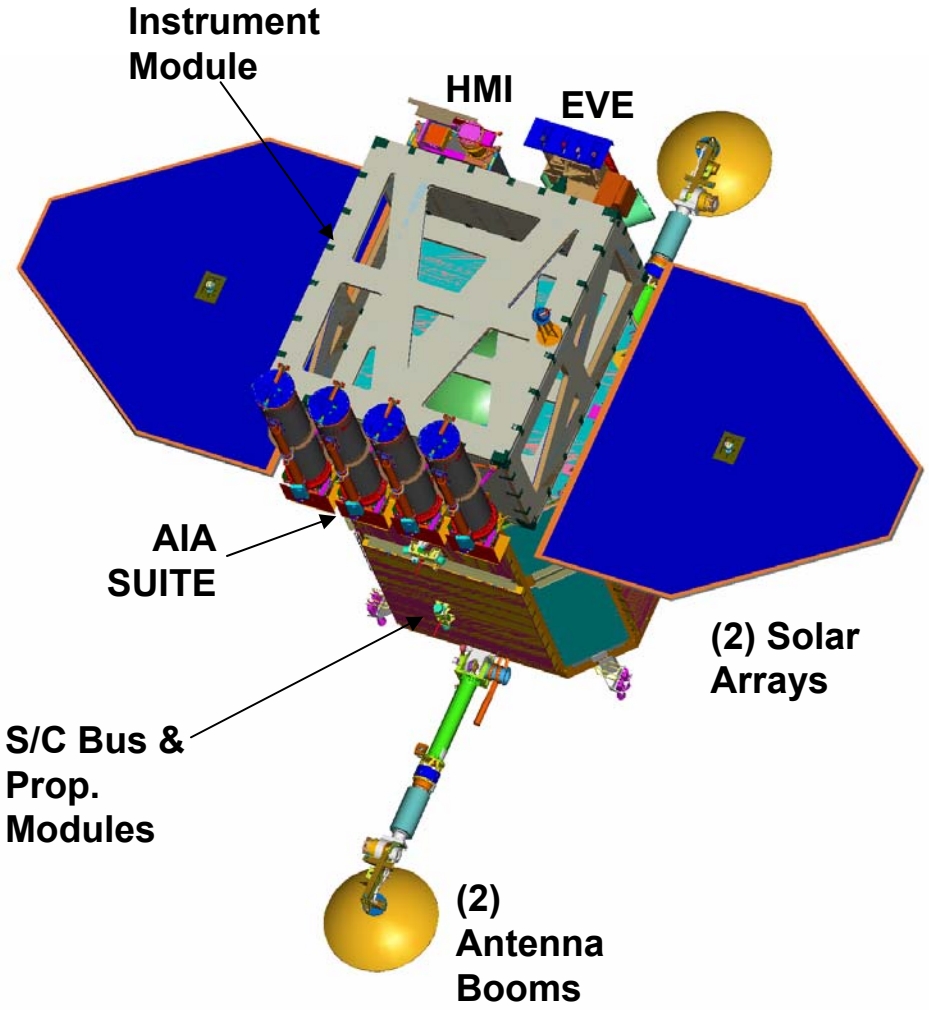
SDO Observatory

SDO Investigations:

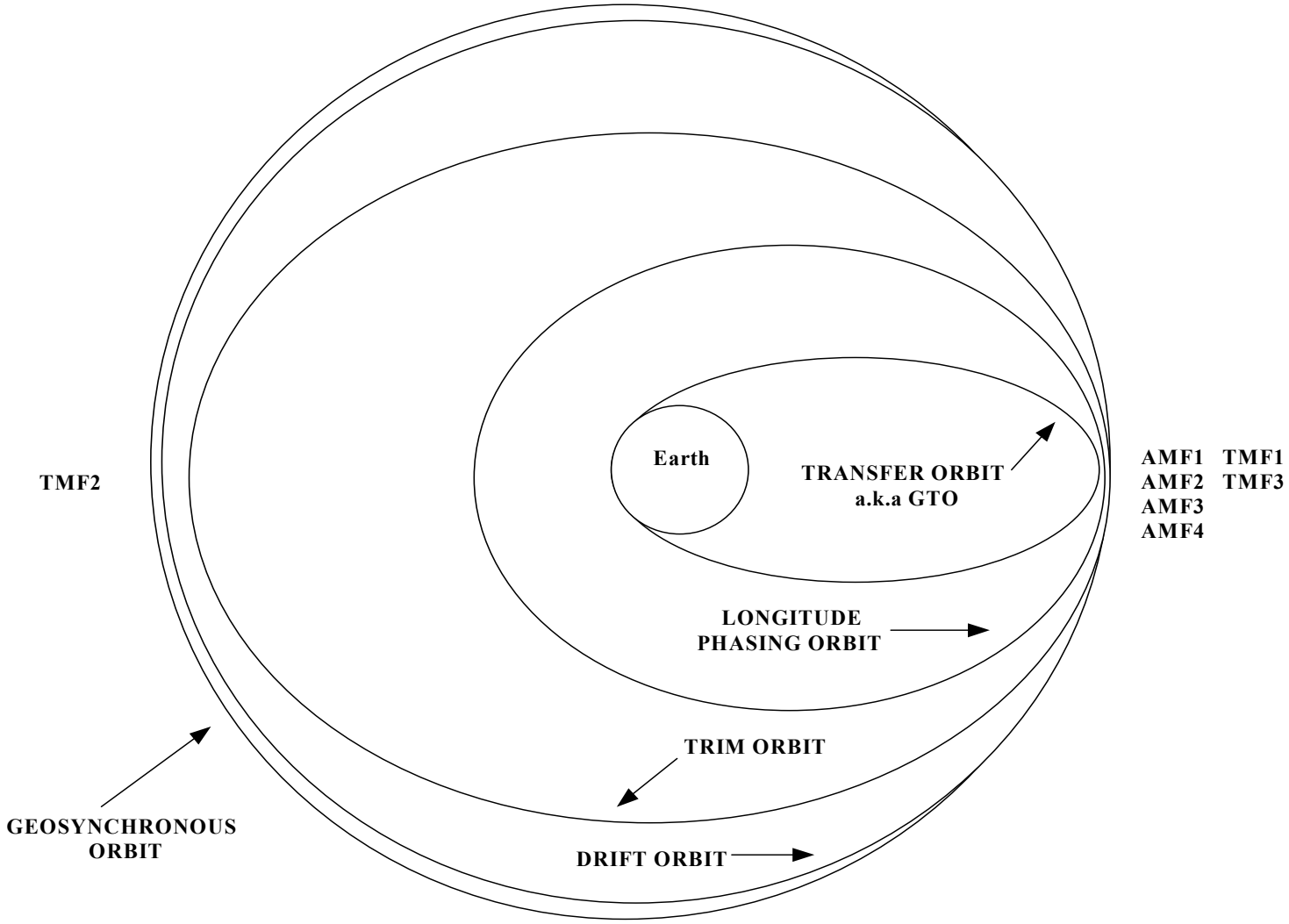
- Helioseismic Magnetic Imager (HMI); PI: Phil Scherrer – Stanford; Images the Sun's helioseismic and magnetic fields to understand the Sun's interior and magnetic activity.
- Atmospheric Imaging Assembly (AIA) and Guide Telescopes (GT): PI: Alan Title – LMSAL; Multiple simultaneous, high-resolution images of the corona over a wide range of temperatures.
- Extreme Ultraviolet Variability Experiment (EVE); PI: Tom Woods – LASP, Univ. of CO; measures the solar extreme ultraviolet (EUV) irradiance to understand variations.

Approximate characteristics:

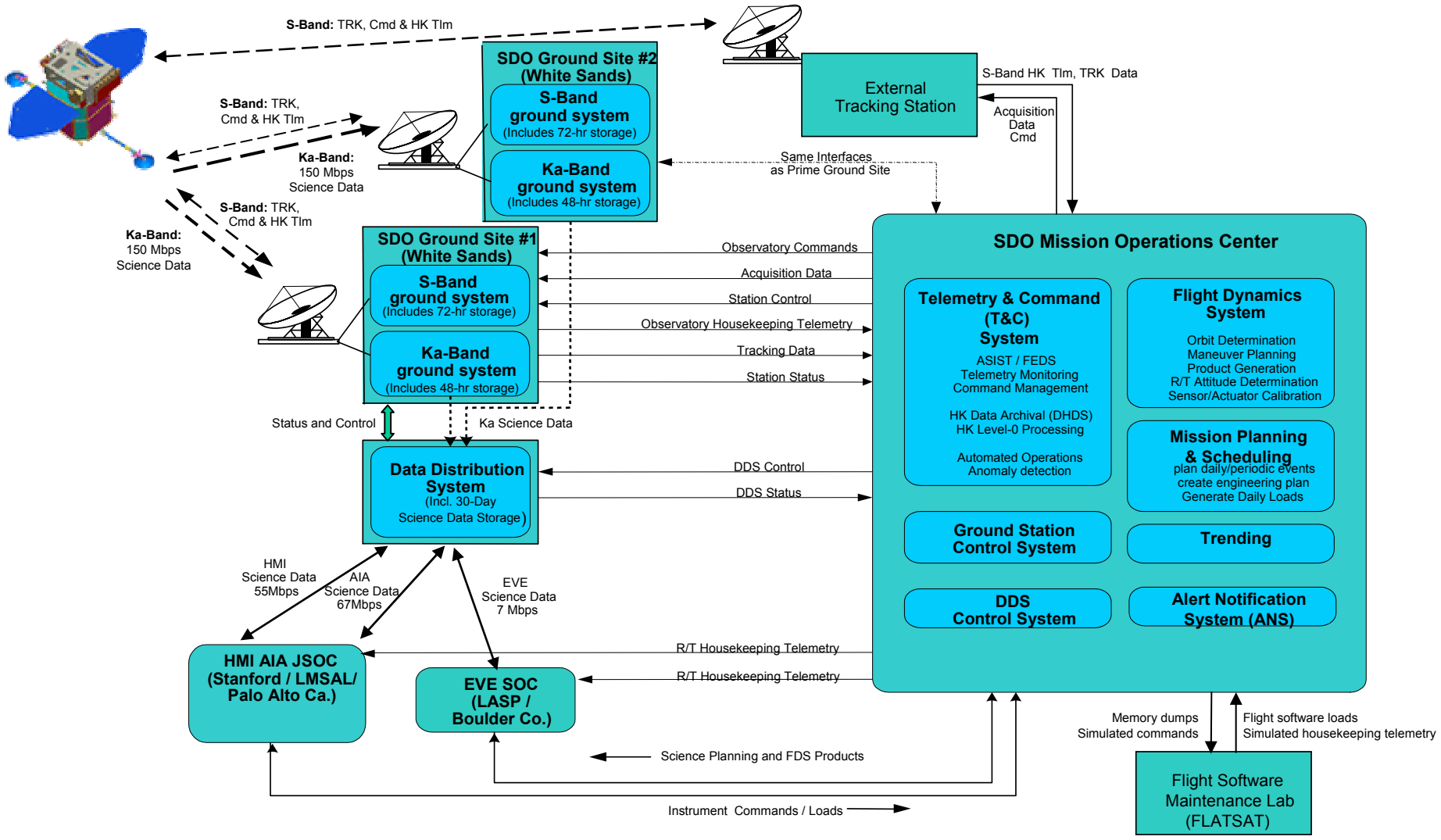
- Mass: 3200 kg, 30% margin
- Width: 2.25 m
- Height: 5.25 m



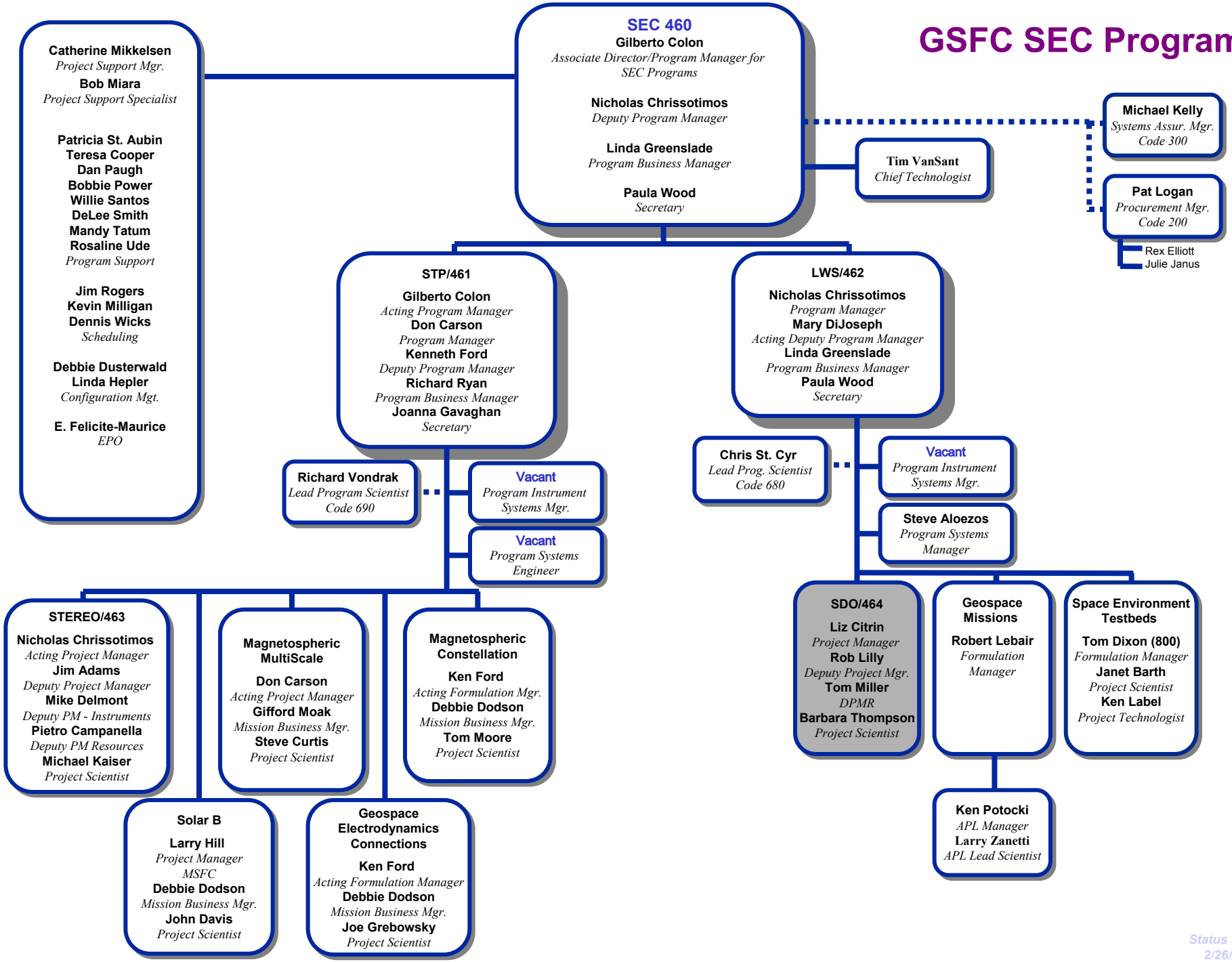
Orbit Raising Diagram



SDO Ground System Architecture



GSFC SEC Program



Status as of 2/26/04

GSFC SDO Project

Barbara Thompson
Project Scientist
Dean Pesnell
Assistant Project Scientist

Liz Citrin
Project Manager
Rob Lilly
Deputy PM
Tom Miller
Deputy PM Resources

Education & Public Outreach
SEC/LWS Program Team

Science Working Team

Eliane Larduinat
Science Support
Jennifer Rumburg
Web Development
Emilie Drobnes
E/PO & Production

John Ruffa
Mission Systems Engr.

Wanda Harrell
Business Manager

Ellen Berkeley
Renee McCaskill
Resource Analyst
Belinda Barker
Terri Lynne Hynson
Jack Arrison
Project Support
Toni Hegarty
Marsha Gosselin
Configuration Control
Jim Perry
Mike Lilly
Scheduling

Barry Murphy
Intranet Development
Barbara Lambert
Photo & Video

Carlos McKenzie
Kathy Tennant
Contracting Officer

Bob Calvo
System Assurance Manager

Carol Hamilton
Rick Stickle
Safety
Matt Samuel
Marvin Roush
Tom Manson
Reliability
Jerry Klein
Risk Management
Mike Garner
Software QA
Mike Jones
Steve Himes
Hardware QA

Dave Ward
Spacecraft Systems Eng.
Manuel Maldonado
Software Systems Eng.
Tom Kenney
GN&C Systems Eng.
Wendy Morgenstern
Deputy GN&C Sys. Engr.
Josephine San
Debris Engineer
Steve Merrihew
Instrument Sys. Eng.
Chad Salo
Instr. Accommodation Eng.
Mike Bay
Pete Gonzales
Systems Support
Sharon Straka
Contamination
Mike Xapsos
Radiation
Dennis Krus
Antonio Reyes
Noman Siddiqi
Parts Engineer
Richard Marriott
Materials

Tom Anderson
Instrument Systems Manager

HMI
Philip Scherrer (PI)
AIA
Alan Title (PI)
EVE
Tom Woods (PI)

Mike Scott
HMI Instrument Mgr.
Eric Grob
AIA Instrument Mgr.
John VanBlarcom
EVE Instrument Mgr.
Tech. Support Team
Ken Lee
Mechanisms
Pete Shu
CCDs

Brent Robertson
Observatory Manager

Wendy Morgenstern
ACS
Gary Davis
Propulsion
Bob Defazio
Flight Dynamics
Rich Hollenhorst
EGSE Systems
Dennis Hewitt
Systems Development Engr.
Kevin Hughes
L.V. I/F & Verification Engr.
David Amason
I&T

Jack McCabe
C&DH
Mike Powers
Ka-Band Comm.
Maria Lecha
S-Band Comm.
Mark Walters
Flight Software
Harry Culver
Subsys Data Node
Amri Hernandez-Pellerano
Subsys Pwr Node

Giulio Rosanova
Mechanical
Dan Nguyen
Dan Powers
Thermal
Rich Barclay
Mechanisms
Denney Keys
Power
Paul Kim
Gary Won
Electrical

Raymond Pages
Ground System & Mission Operations Manager

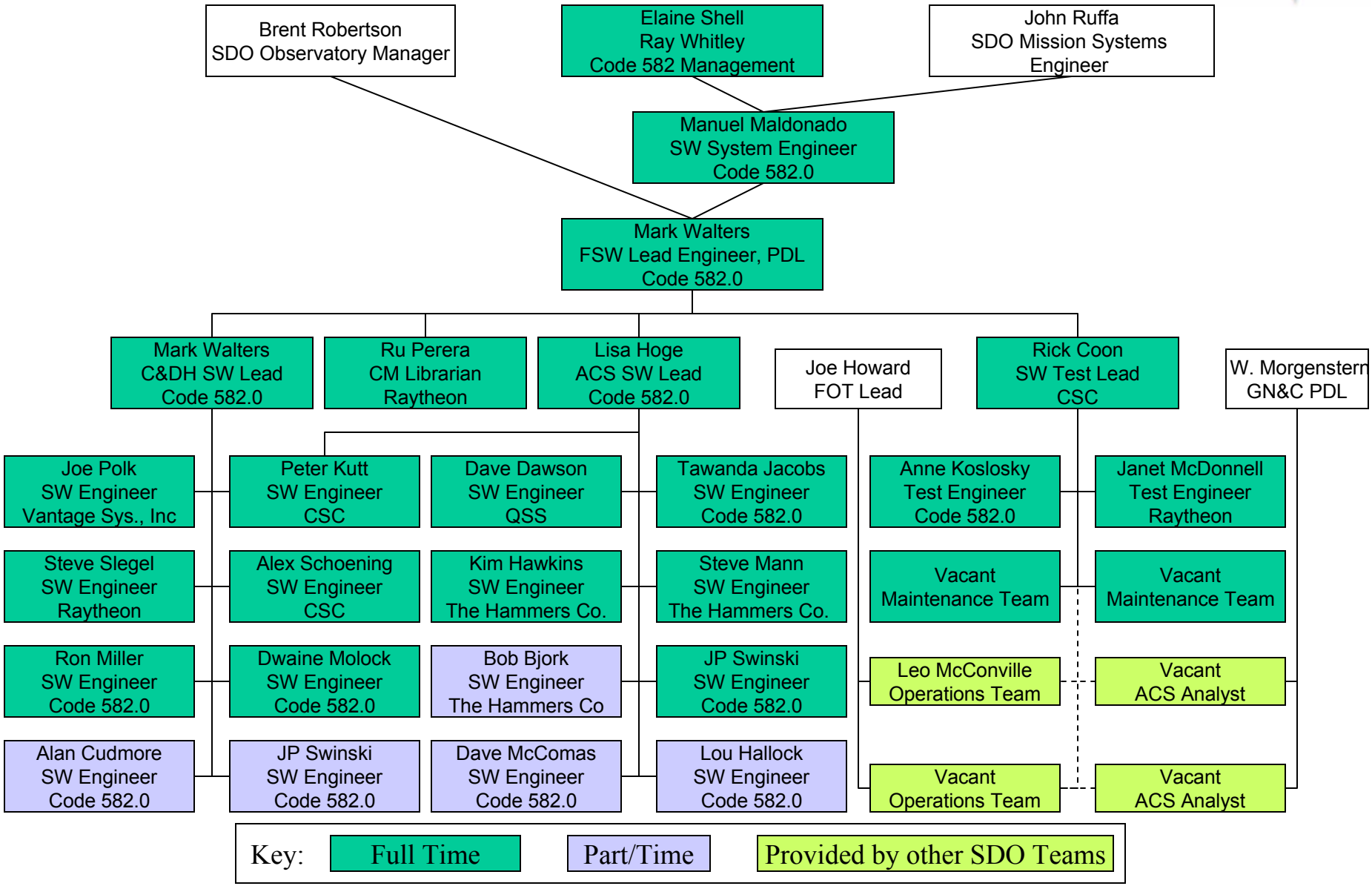
Bill Potter
Deputy Gnd Sys. Mgr.
Hun Tann
MOC Implementation
Jeff Ferrara *Flight Operation*
Joe Howard *FOT*

Tom Bialas
Mike Uffer
Data Distribution
Marco Midon
Antenna/Facility
Chris Spinolo
Network & Comm.
Robert Oertly
Test & Verif.

Craig Weikel
Eliane Larduinat
Stephania Young
Frank Scooville
Systems Engineering

Update: 03/01/04

Organization



FSW Systems Manager Role

- **Report to the Missions Systems Manager, part of the System Engineering Team**
  - Ensure that FSW issues are considered at the systems level and are tagged as risks if they meet the project risk criteria
- **Responsible to FSW Branch for 582 Branch Contributions to SDO**
  - FSW Development for Spacecraft Bus (Main Processor, PSE, ACE, GCE, S-Band)
  - Testing (Verification and Validation)
  - FSW Maintenance Planning
- **Assist SDO Project Instrument Systems Manager in evaluating Instrument FSW Development Plans, Schedule and program Execution by providing FSW Discipline Technical and Management Expertise**
- **SDO Project IV&V Point of Contact and Project Gatekeeper for IV&V Requests**
- **Responsible for the Design of the Instrument to Spacecraft Interfaces**
  - Instrument to Spacecraft Housekeeping and Diagnostics Telemetry (1553)
  - Spacecraft to Instrument Commanding (1553)
  - Instrument to Spacecraft Science Data Interface (HSB)
- **Contributor to Design of the Observatory to Ground Interfaces**
  - Ground to Observatory Command Data Interface (CCSDS)
  - Observatory to Ground Ka-Band Science Data Interface (CCSDS)
  - Observatory to Ground S-Band Housekeeping Data Interface (CCSDS)
- **SDO CCSDS Implementation**
  - Time Epoch
  - Spacecraft ID

FSW Systems Engineering

- **Major Contributor to SDO FSW Product Plan with PDL**
  - Schedule, budget, manpower, development processes and guidelines
- **Contributed to FSW Allocated Requirements in Mission Requirements Document**
- **1553 Bus ICD and Schedule Allocations**
- **Contributor to Spacecraft Timekeeping and Time Distribution (1553)**
  - Observatory to Ground Correlation (S-Band SDN)
- **Spacecraft Telemetry Monitoring and Responses**
- **Telemetry Rate Allocations and Telemetry Packet Design**
- **Spacecraft Simulators Requirements**
- **Contributed to Defining FSW Sub-System Requirements**
- **Contributed to Telemetry and Command System Selection Criteria (ASIST)**
- **Reports to Branch any Problems or Issues in Areas of Oversight**

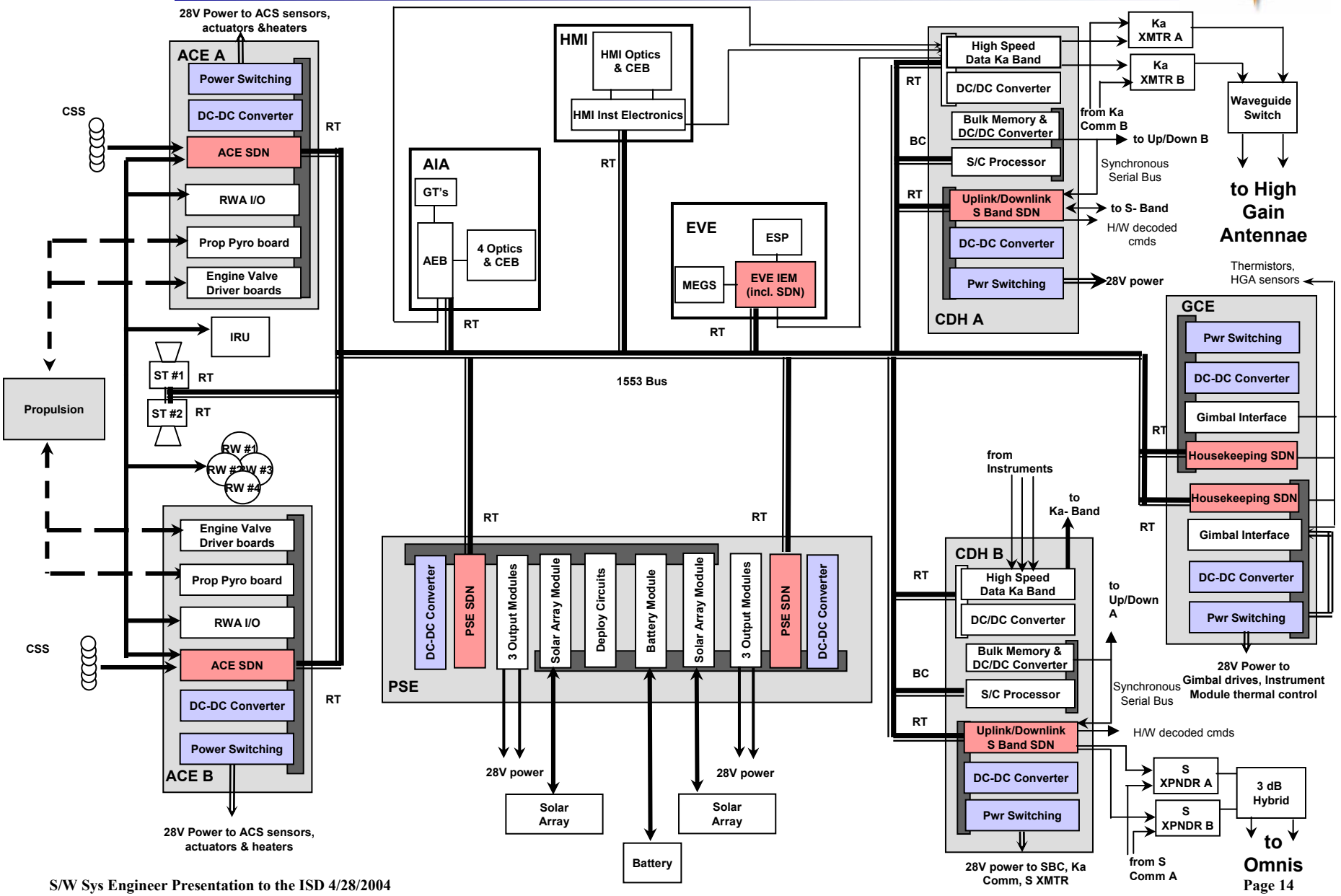
SDO IV&V

- **Signed MOU in place with IV&V**
- **SDO Completed Self Assessment Process**
  - Self Assessment end result was that SDO needed an Initial Assessment to evaluate which of the various SDO software development projects warrants more scrutiny
- **IV&V has completed Initial Assessment on S/C Bus and Instrument Flight Software (Not Ground System)**
  - Project S/C Bus and EVE and HMI Instruments have completed initial assessment surveys
- **IV&V, SQA and Software Systems have weekly tele-conferences to coordinate work, share concerns**
  - Instruments and Spacecraft Bus FSW Lead have been added
- **IV&V has attended and continues SDO and Instrument reviews**
- **Currently trying to reach agreement on CFL so that SDO project can sign MOA on IV&V Project Plan**

SDO FSW and SQA

- First time SQA has taken an interest in a mission I'm working on.
- SQA has had lots of manpower turnover, currently on 3rd SQA person for SDO
- Initial agreement was for SQA person to help by recording action items at requirements reviews and code inspections and help in getting these items closed and documented
- SQA person realized this is lots of work and decided not to continue performing this function with us
- Currently in conversations with SQA management to clarify role

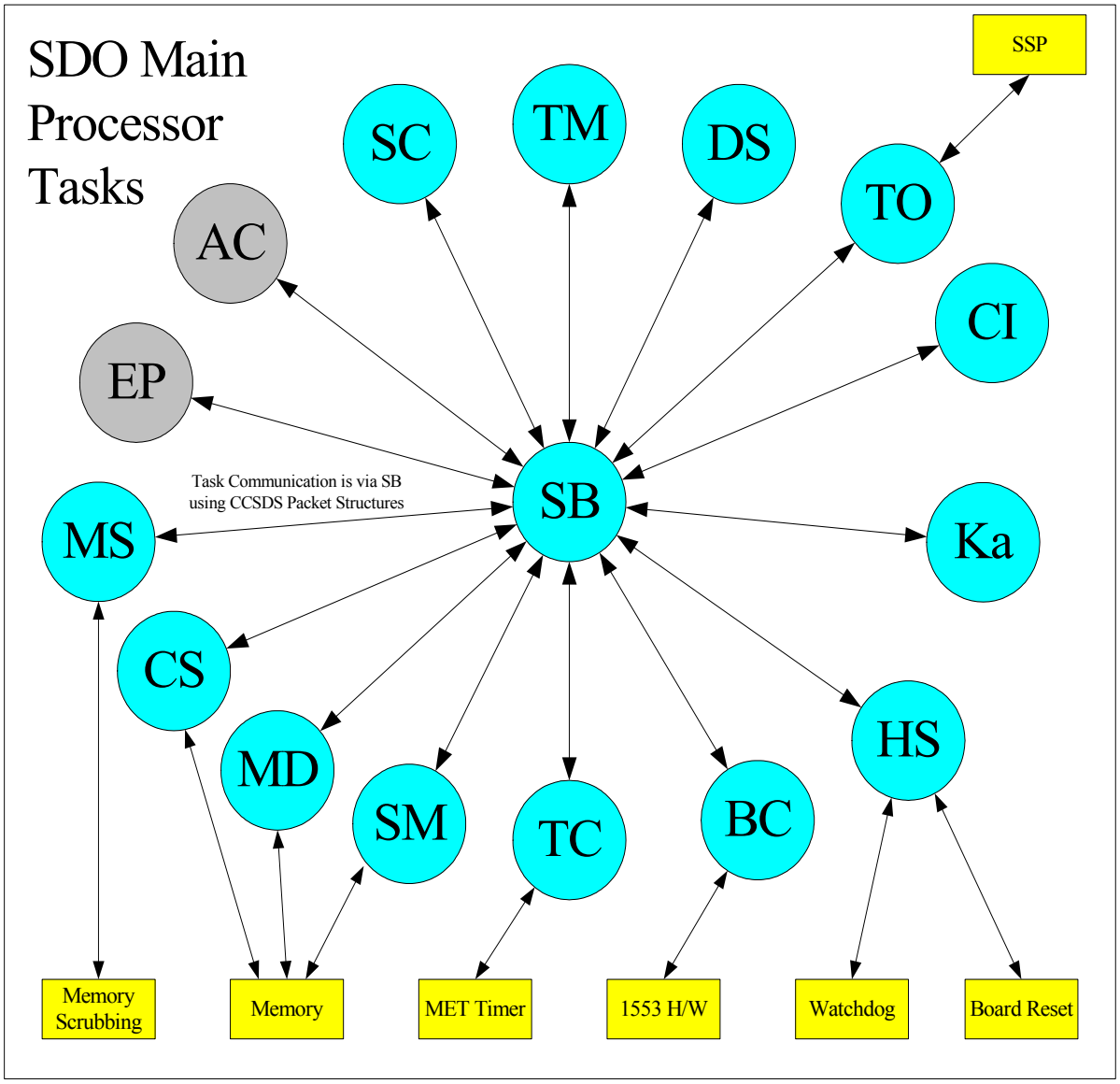
SDO Electrical Architecture



FSW Preliminary Design Overview

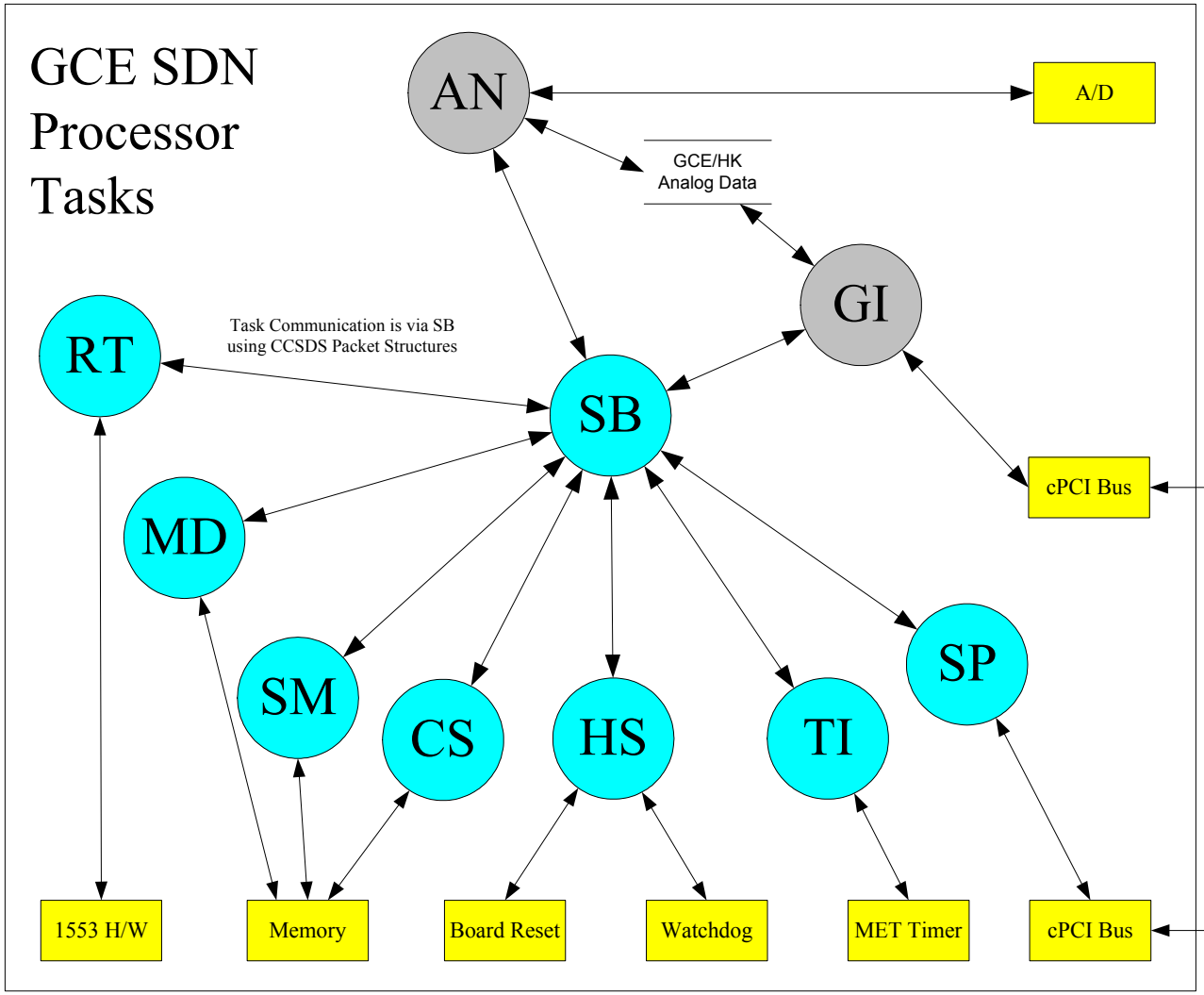
- **S/W Architecture**
  - Main Processor Software Bus Architecture derived from MAP/EO-1 Architecture
    - Software Bus is a set of inter-task communications functions and routing tables that use CCSDS packets as the basic data structures sent and received by tasks
    - CCSDS Packet Application Identifiers (apid's) are used to determine the routing(s) of packets between tasks
  - Matches and Complements Hardware Architecture
  - Distributed Software System Simplifies Development, Testing and Integration
  - Common High Level (C Language) Software across SDNs and Main Processor
    - Parallel testing of common software will result in a more robust product
- **Software Developed in the C Language using a structured development methodology**
- **COTS Real Time Operating Systems**
  - VxWorks on Main Processors
  - RTEMS on SDNs
- **Where hardware differences require software redesign, add a hardware abstraction layer API to buffer software from future hardware changes**

Main Processor FSW Architecture



SB-Software Bus
SC-Stored Commands
TM-Telemetry Monitor
DS-Data Storage
TO-Telemetry Output
CI-Command Ingest
Ka - HSB FDC
HS- Health & Safety
BC-1553 Bus Controller
TC-Time Code
SM-Software Manager
MD-Memory Dwell
CS-Checksum
MS-Memory Scrub
EP-Ephemeris
AC-Attitude Control & Failure Detection and Correction

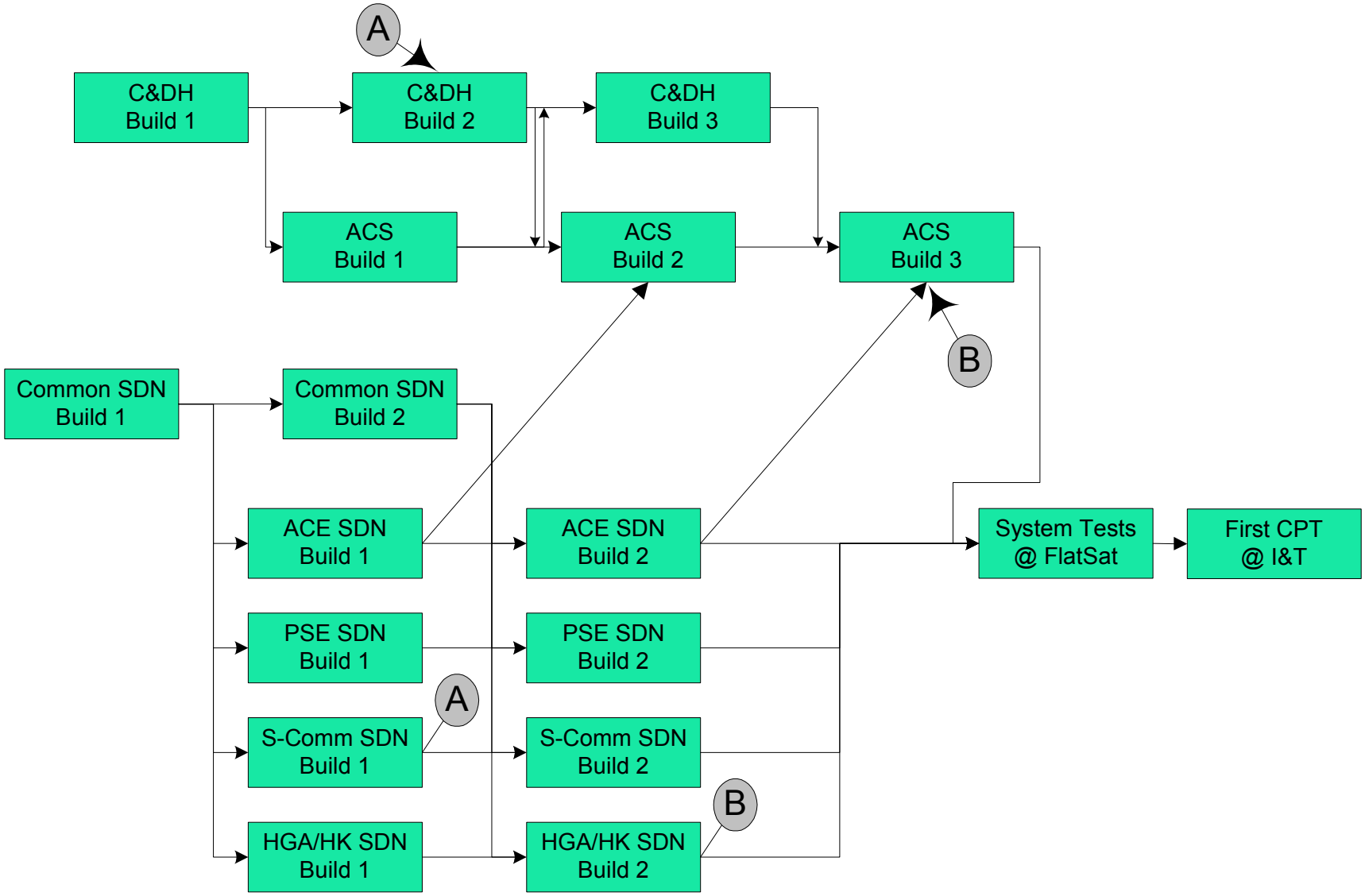
GCE SDN FSW Architecture



SB-Software Bus
HS-Health & Safety
CS-Checksum
SM-Software Manager
TI-Time Code
RT-1553 Remote Terminal
SP- Switch Card
MD - Memory Dwell

GCE SDN Tasks
AN - Analog Tlm Task
GI- Gimbal/HK Task

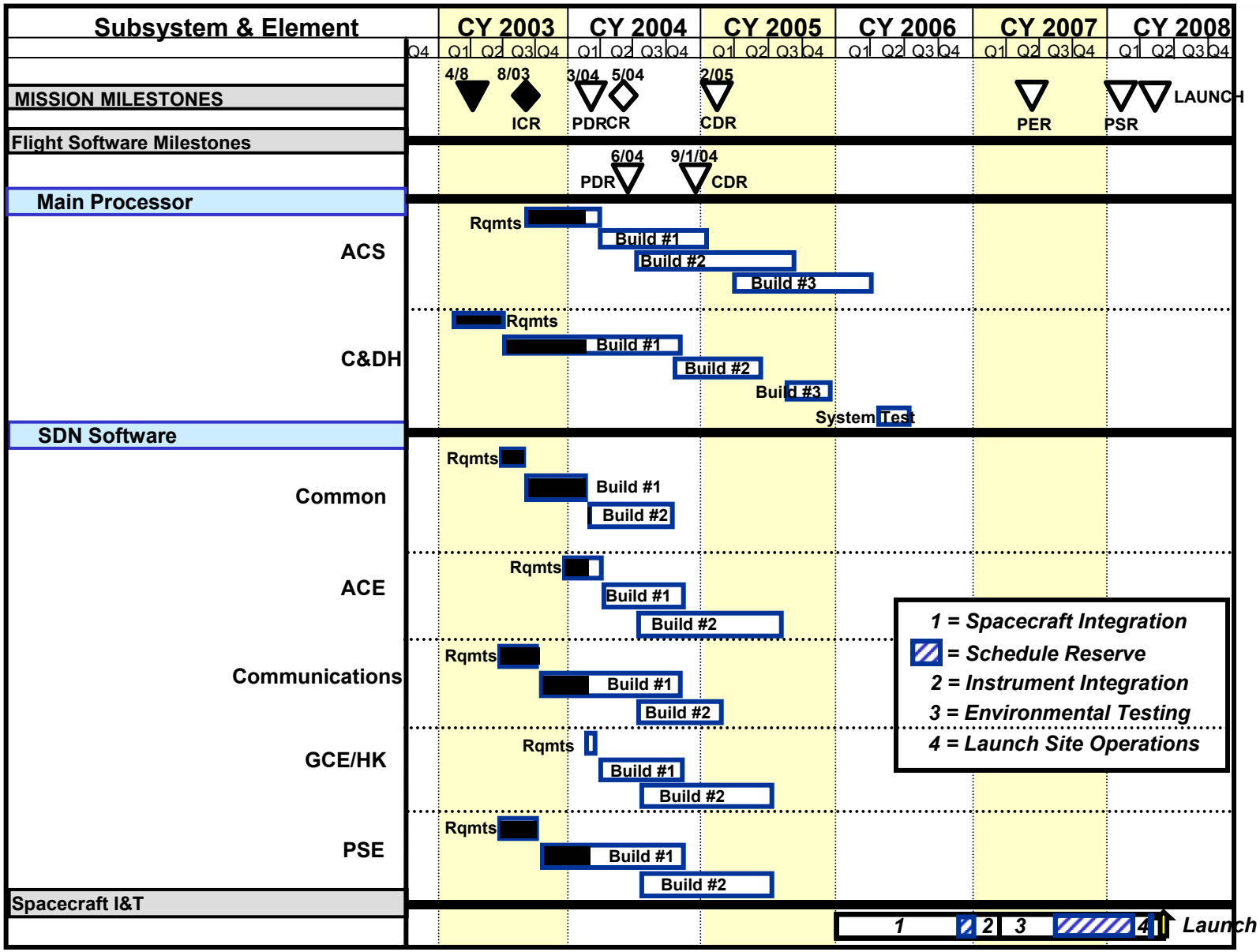
Software Development Flow



FSW Build Content

- **Main Processor C&DH Builds**
  - C&DH Build 1
    - •OS, SB, TC(partial), HS, 1553 BC, CI, TO
  - C&DH Build 2
    - •TC(final), MD, CS, MS, SM
  - C&DH Build 3
    - •SC, DS, TM, Ka
- **Main Processor ACS Builds**
  - ACS Build 1
    - •Ground Commands, Modes Framework and AutoCode hooks
    - •Sensor data processing (primary and redundant)
    - •Open Loop Commanding RW and EVD
  - ACS Build 2
    - • ACS Mode management and closed loop controllers
    - • FDC(partial) Checks
    - • Attitude Initialization and Determination
  - ACS Build 3
    - • Kalman Filter and Controller updates
    - • HGA Commanding and Telemetry Processing
- **Common SDN Builds**
  - Build 1
    - • OS, SB, RT, HS
  - Build 2
    - • SM, TC, CS, MD
- **ACE SDN Builds**
  - Build 1
    - • 5H - Raw Sensor Telemetry Collections & Open Loop Actuator Cmds and Tlm
    - • AC - Asynchronous Commands
    - • AH - ACE Analog Telemetry
  - Build 2
    - • 5H - SAFEHOLD
- **PSE SDN Builds**
  - Build 1 - Switch Commands, Analog Telemetry Deployment actuator command, separation switch telemetry
  - Build 2 - BSOC Computation, Battery Charging control loop, FDC of PSE critical telemetry
- **GCE/HK SDN Builds**
  - Build 1
    - • AN - HK and Gimbal Telemetry
    - • GI - “Open Loop” Gimbal Commands
  - Build 2
    - • GI - “Rate Controlled” Gimbal Commands
- **S-Band SDN Builds**
  - Build 1
    - • UL- Code Block Processing
    - • DL- Real Time Telemetry Downlink
    - • AN - C&DH Analog Telemetry
  - Build 2
    - • DL - Transponder Commands and Telemetry
    - • GC - Time correlation

Flight Software



FLATSAT Use and Concept

- **Before Launch FLATSAT will be used for:**
  - Acceptance and System testing of the FSW Initial Testing of TSM and RTSs
  - Mission Simulations, Verification of STOL Procedures for I&T, Launch and Operations
  - Harness Integration Verification
  - Anomaly Investigation
  - Interface test of BB/ETU/Flight Instruments or components
- **After Launch FLATSAT will be used for:**
  - FSW code and table Update Development and Verification
    - •TSM and RTSs updates
    - •General Table updates (ACS, etc)
    - •Code updates
  - MOC Verification of New Procedures
  - Anomaly Investigation

- **Single String ETUs of Spacecraft Bus Components connected**
  - C&DH Box
  - PSE (one full side populated)
  - GCE
  - ACE
- **Flight Like Harness**
  - Power distribution
  - 1553 Bus
  - Hardware commands
  - Hard line telemetry and commands
  - Test Connector harnesses from ETUs to EGSEs
    - •RS-422 ports on SDNs and SBC
- **Dynamic Simulator**
  - Analog Stimulus of RW, IRU, CSS, Thrusters
  - Digital Simulation of ST, ACE
  - Simulation of gimbals/encoders
- **RT Simulator for Redundant ETUs, Instruments, Ka-Band Card on 1553 Bus**
- **S-Band and Ka Band FEDS and ASIST Workstations**
- **To be housed in B23/N410 Flight Software Lab**
- **Built, Integrated and Maintained by I&T team**
- **Scheduled by FSW Test Team Lead**
- **End to End Science Data Flow Verification**
  - Science Data HSB simulator,
  - Ka Comm in CDH,
  - Ka Feds
  - DSS in GDS)

Issues and Concerns

- **Late delivery of SDN BB to FSW lab**
  - Late delivery to EVE, and possible impact to other SDN FSW Deliveries
- **Actel PCI core**
  - Missing address translation feature that all commercial cores have
  - Bug in design - an interrupted transfer crashes the state machine
    - Will need to work around
  - Ability to discern the PCI source (A, B, C or D) of the interrupt
    - Working on a fix
- **Possibly Loosing 2 ACS Developers (Contractors) to Help Steve Scott in Shuttle return to Flight work**
  - Working with Hammers and Branch to find replacements
  - Need replacements that are familiar with MAP ACS Code Framework
- **SBC Procurement and Delivery for FSW Development**
  - 2 SBC representative designs have been procured
- **Stored Command Processor Time Resolution**
  - Working with System Engineering to determine SDO Requirement
- **Ka-Card and HSB FDC**
  - Working with Ka-Comm engineers to baseline an FDC algorithm for HSB

Instrument FSW

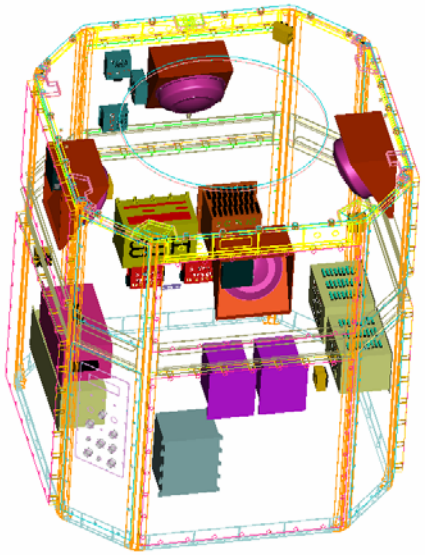
- **EVE - LASP**
  - GSFC/SDO/Code 560/590 Provided SDN Processor Board ColdFire RH-5208 @ 24 MHz, 2 MB of SRAM, 2 MB of EEPROM 64KB of PROM
  - GSFC/SDO/Code 582 delivering SDN Common Code to provide:
    - 1553 RT
    - Time synchronization
    - Memory and table loads and dumps
    - Software Bus
    - Watchdog management, event message monitoring, cold and warm restarts
    - Static memory Checksumming
    - Memory Dwell Diagnostic capability
    - Event messages
    - RTEMS RTOS and mode manager
  - GSFC/SDO/Code 582 provided Software Development Tools for SDN development
  - GSFC/SDO/Code 582 to provide ASIST tests for common code, telemetry and command RDLs and display pages, Tools for making patches, etc.
  - LASP is Developing code to provide
    - Stored Commands processing - we are giving them our SCP, but are not responsible for integration
    - Instrument control and commands
    - Instrument Telemetry

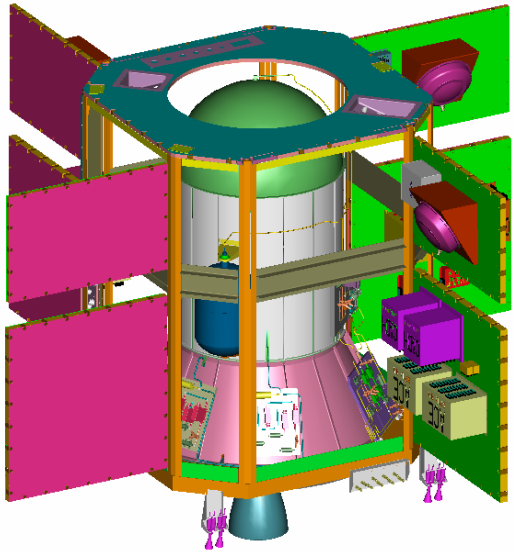
Instrument FSW

- **HMI - Stanford University & AIA - Lockheed Martin**
  - One LM Team is developing both HMI and AIA Instruments FSW
  - CMM Level 3 certified
  - They are developing a core of software common to both HMI and AIA
    - Messaging bus - similar to our Software Bus
  - HMI and AIA are using identical redundant BAE RAD6000 @ 32 MHz Processor , 4 MB SRAM, 512KB EEPROM, 64KB PROM, PCI interface to one other card, 1553 I/F on PCI Card
  - (Start-Up)SUROM Mode in PROM
    - Boots and can accept memory load commands over 1553
    - Minimal telemetry and commands - no science operations, for loading code and troubleshooting only
  - FSW Mode in EEPROM
    - Loads VxWorks Kernel and FSW image from file system on EEPROM
    - Can load code into EEPROM
    - Runs telescope image taking sequences

Backup Slides

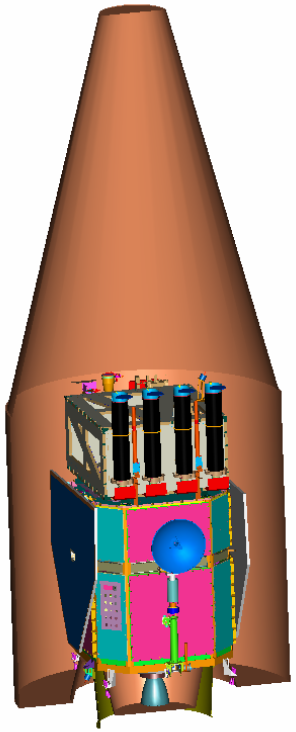
SDO Spacecraft Bus





Delta IV

4 m dia.
Fairings



Atlas V

HMI - Helioseismic and Magnetic Imager

PI: Phil Scherrer, Stanford Univ.

HMI Overview: The primary scientific objectives of the Helioseismic and Magnetic Imager (HMI) investigation are to study the interior sources and mechanisms of solar variability and to study the relationship of these internal physical processes to surface magnetic field structure and activity.

Measurement Requirements: **(a)** Stabilized ~1 arcsec resolution full-disk Doppler velocity and line-of-sight magnetic flux images at least every 50 seconds for Helioseismology studies and **(b)** Stabilized ~ 1 arcsec resolution full-disk vector-magnetic images of the longitudinal solar magnetic field at least every 90 seconds for magnetic variability studies

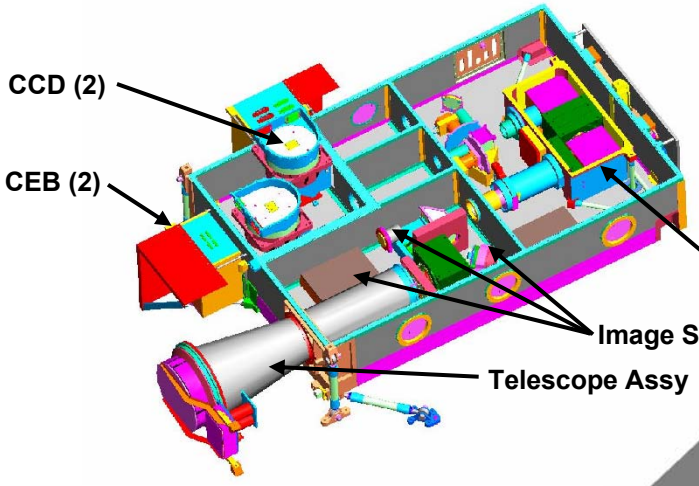
Project Drivers: Development of 4k x 4k CCDs and companion readout electronics.

HMI implementation:

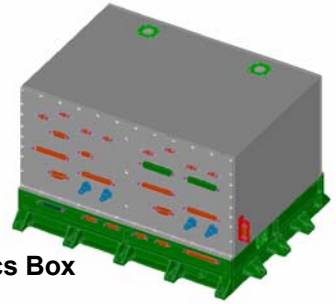
- Stanford University is lead institution and provides the Science Operations Center, science team coordination, helioseismology and magnetic field science, and E/PO
- Lockheed-Martin Solar and Astrophysics Lab provides HMI instrument and magnetic field science

Current Status: Successfully completed PDR

Heritage: MDI, FPP, SECCHI and SXI



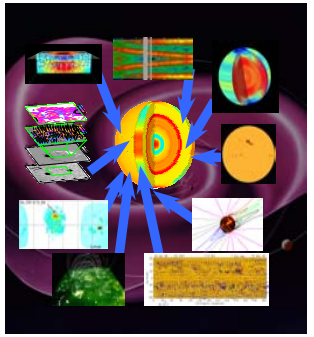
HMI Optics Package Assembly



HMI Electronics Box

Key Milestones

Milestone	Status
Phase A	Completed
PDR	Completed
CDR	Nov 2004
Optics Package Alignment	Dec 2005
HMI Calibration	Mar 2006
HMI Complete	June 2006
Delivery	Nov 2006



AIA – Atmospheric Imaging Assembly

PI: Alan Title, LMSAL

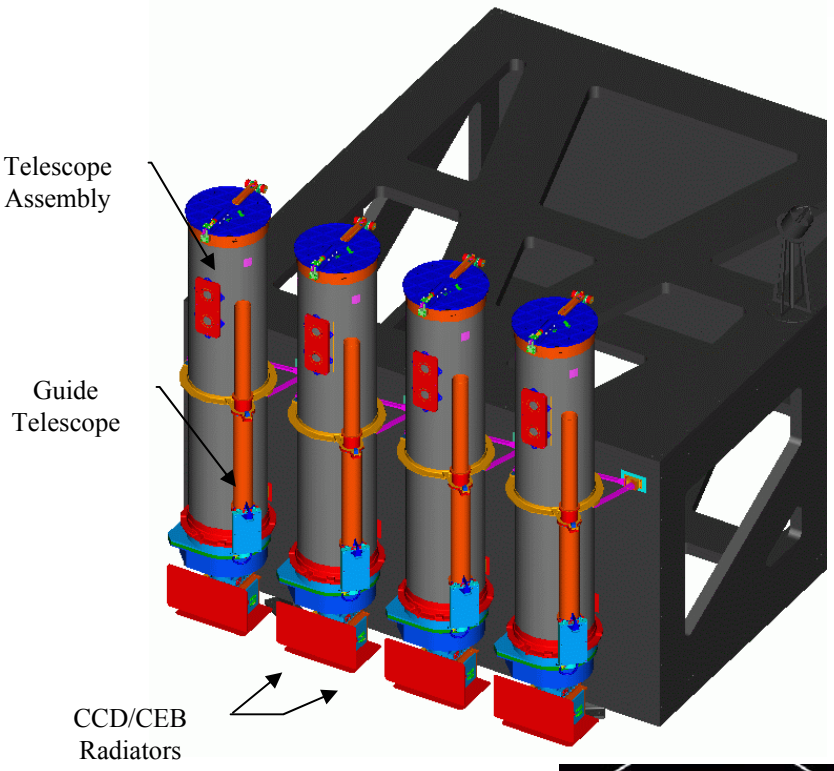
AIA Overview: AIA studies the active dynamics of the solar atmosphere in high spatial resolution and high temporal cadence in several spectral (and therefore temperature) regions including the extreme ultraviolet (EUV). AIA focuses on the evolution of the magnetic field in the Sun's atmosphere and its interaction with embedded and surrounding plasma including the flaring and non-flaring corona.

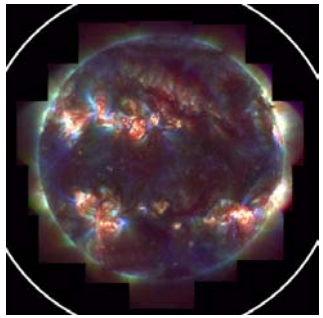
Measurement Requirements: AIA measures stabilized full-disk ~1.2 arcsec resolution images of the solar chromosphere, transition region and inner corona over a temperature range of 0.005 to 20 MK in eight spectral channels with an image cadence of 10 seconds. This will allow discovery of the causal relationship between the relatively slow magnetic field revolution and energy storage, and the rapid energy releases in flares and CME's, which have a direct effect on earth's environment.

Project Drivers: Development of 4k x 4k CCD's and associated readout electronics, and the schedule recovery from the late inclusion of AIA on the SDO mission.

AIA Implementation: Lockheed Martin Solar Astrophysics Laboratory (LMSAL) is responsible for the AIA investigation including the development, delivery and operation of the AIA instrument and the development and conduct of the AIA science data processing. The Smithsonian Astrophysical Observatory (SAO) is a key partner (subcontractor) both scientifically and in development of major instrument subsystems.

Current Status: A definitized contract was established February 12, 2004 for Phases A and B.





Heritage: TRACE, SOHO/EIT

Milestones:
Nov '03: Ltr. Contract; begin Phase A
Mar '04: PDR-1
Apr '04: PDR-2
Nov '04: CDR
Feb '07: Deliver to GSFC
Apr '08: Launch

EVE - EUV Variability Experiment

PI: Tom Woods, LASP/CU

Instrument Overview: EVE measures the solar extreme ultraviolet (EUV) irradiance as needed for Space Weather operations and critical for LWS geospace research of the ionosphere and thermosphere.

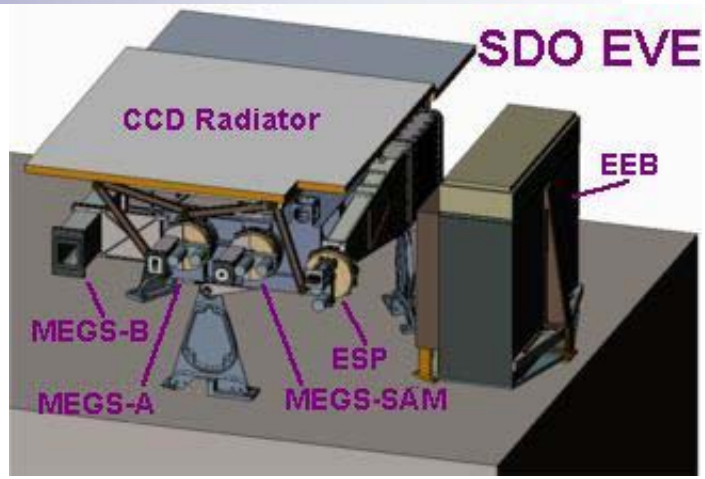
Measurement Requirements: Measure the solar EUV irradiance shortward of 105 nm, with 0.1 nm resolution longward of 10 nm, with 20-sec time cadence, and with 25% absolute accuracy over the prime 5-year mission.

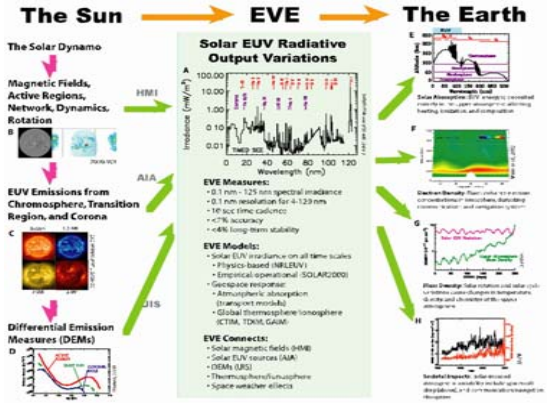
Project Drivers: Obtaining 1024 x 2048 CCDs from MIT on schedule, obtaining flight gratings on schedule, obtaining SDN and S/C Simulator electronics from GSFC on schedule, and new CCD radiator design (prototype radiator under test now).

Current Status: In Phase B, preparing for PDR (Dec. 17/18). Also, descoped the OFS subassembly as risk mitigation for schedule. Replaced the OFS in-flight calibration capabilities by extending ESP spectral coverage, adding zeroth-order diode traps for MEGS, and requiring annual underflight rocket calibrations. Has little or no impact on science, budget, or schedule.

Task Milestones/Products:

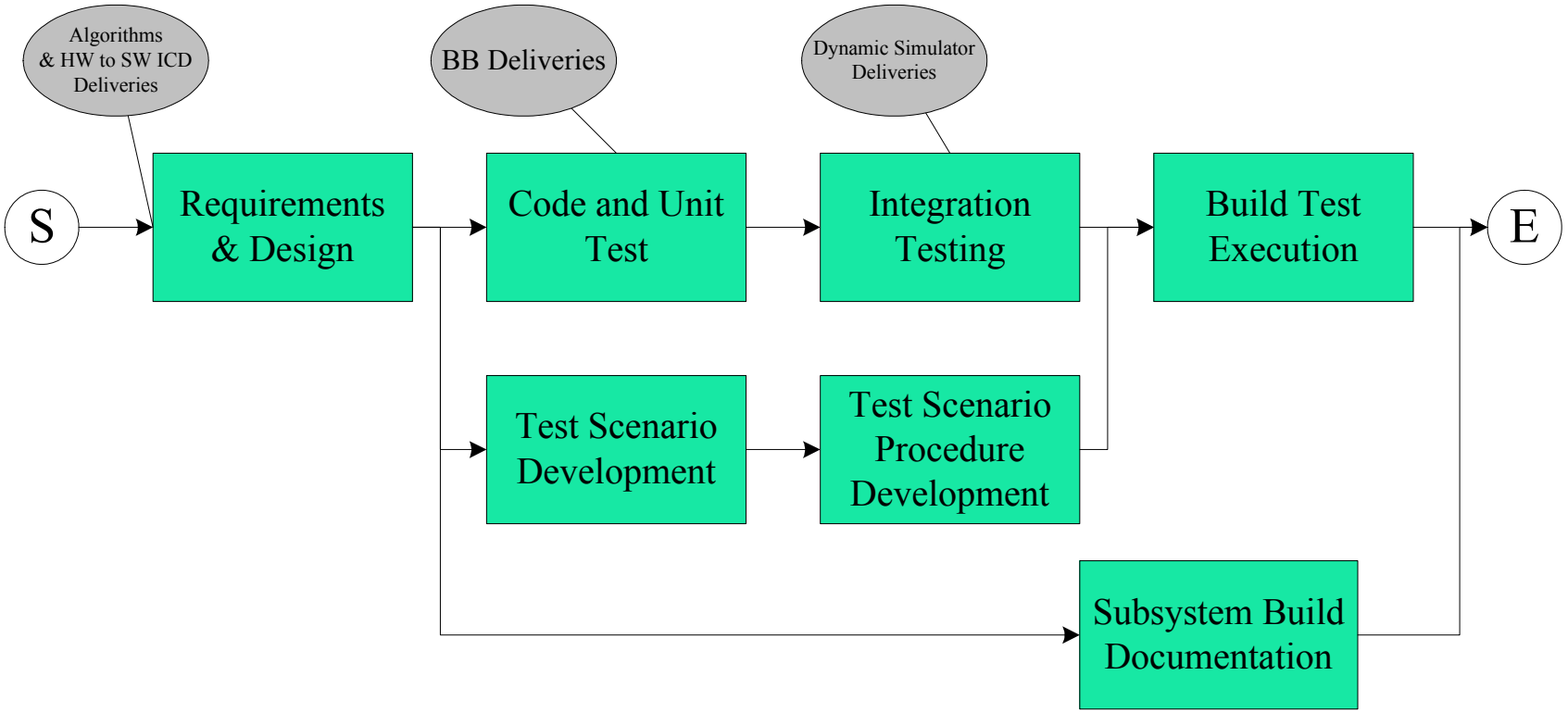
Sept. 02	Began Phase A
July 03	Completed Concept Study Report (Phase A)
Dec. 17-18	EVE Preliminary Design Review (PDR)
Sept. 04	EVE Critical Design Review (CDR)
Nov. 06	Delivery to GSFC



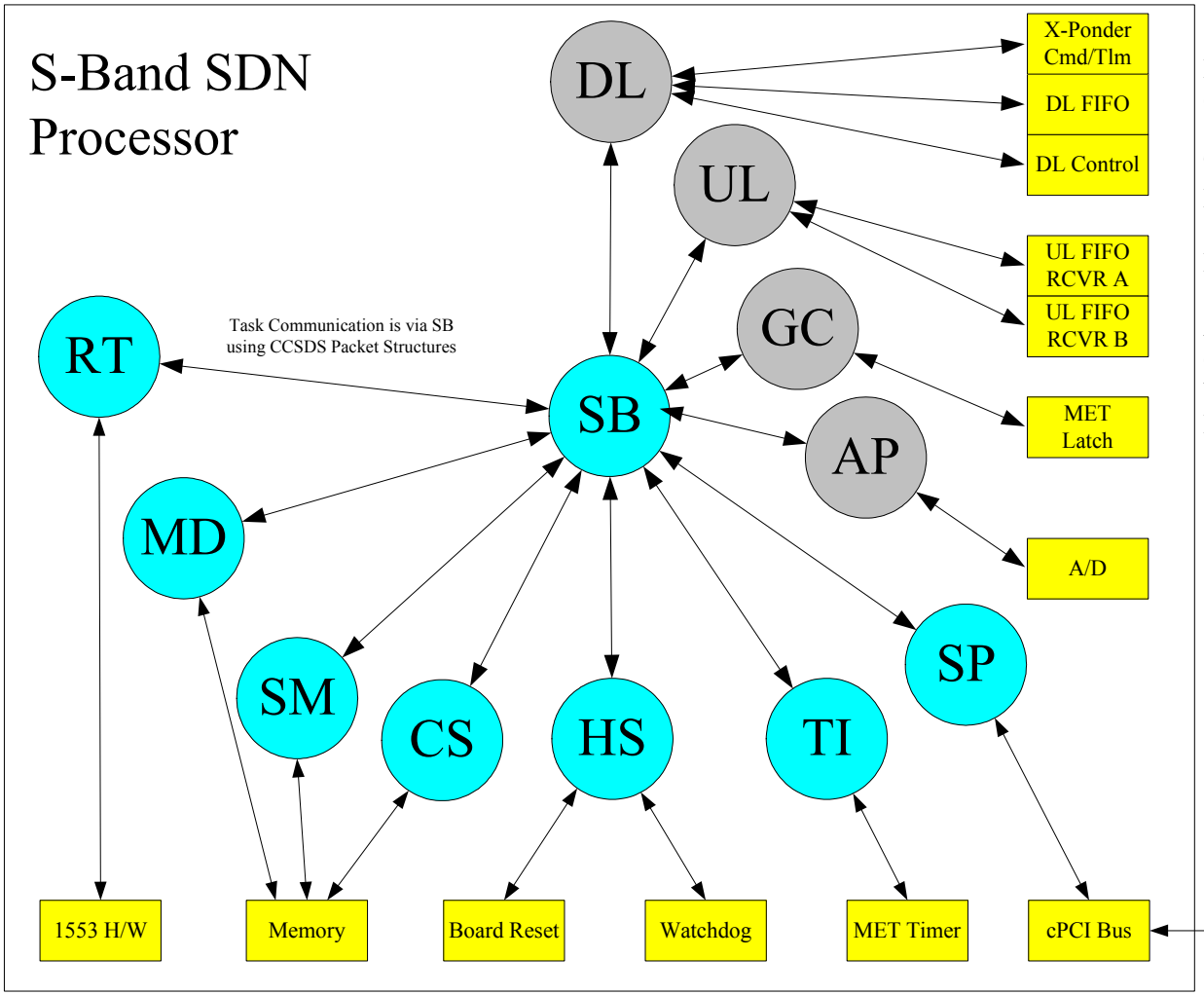


Channel	λ (nm)	Δλ (nm)	Time Cadenc
MEGS-SAM	0.1 - 7	1	10 sec
MEGS-A	5 - 37	0.1	10 sec
MEGS-B	35 - 105	0.1	10 sec
ESP	0.1-7 & 17 - 63	2- 7	0.25 sec
MEGS-P (ZOT)	5 - 85 & 121.6	8 - 30	0.25 sec

FSW Development Flow



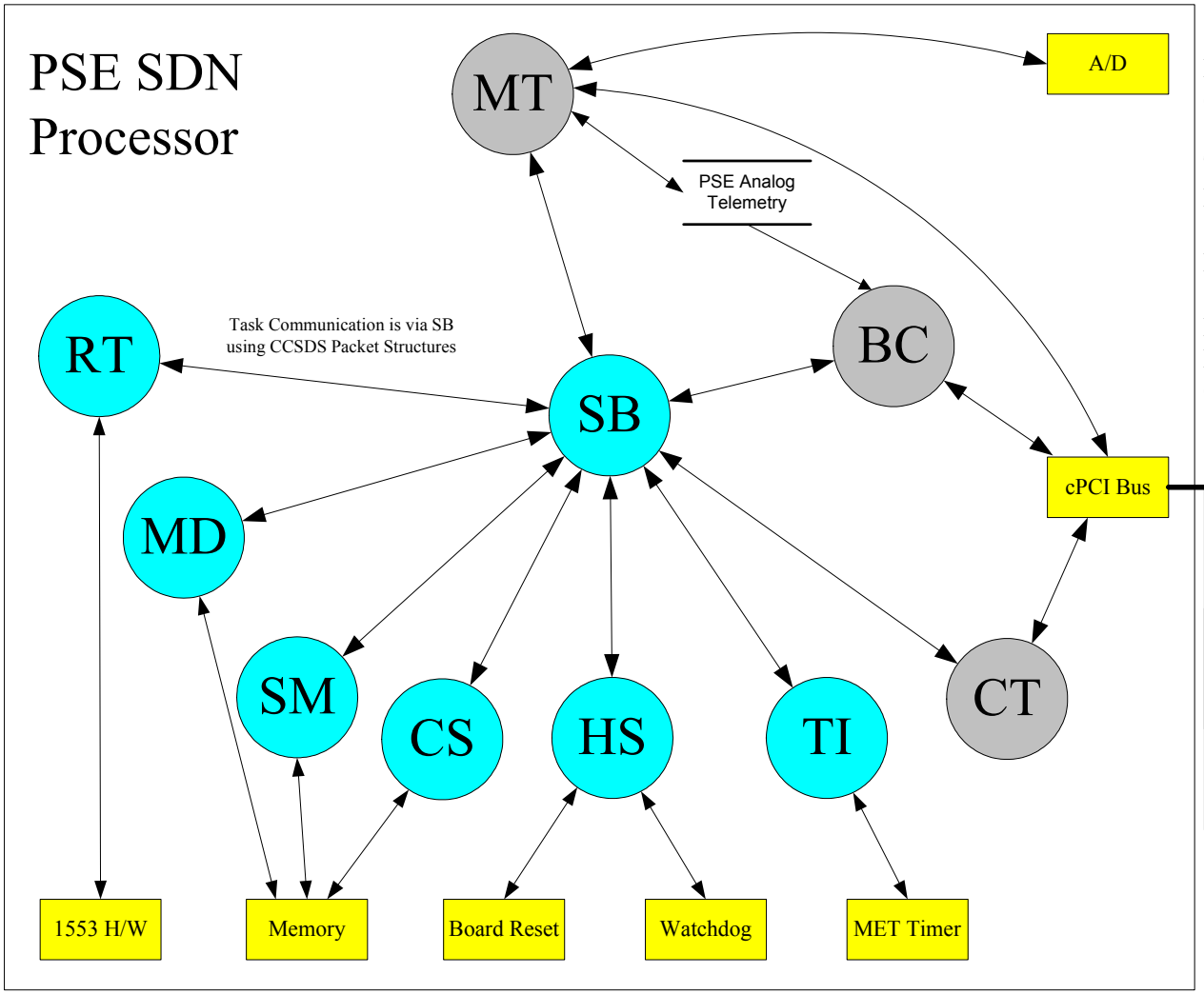
S-Band SDN FSW Architecture



SB-Software Bus
HS-Health & Safety
CS-Checksum
SM-Software Manager
TI-Time Code
RT-1553 Remote Terminal
SP- Switch Card
MD - Memory Dwell

AP- Analog Processing
GC- Ground Correlation
UL- Uplink
DL- Downlink & X-Ponder

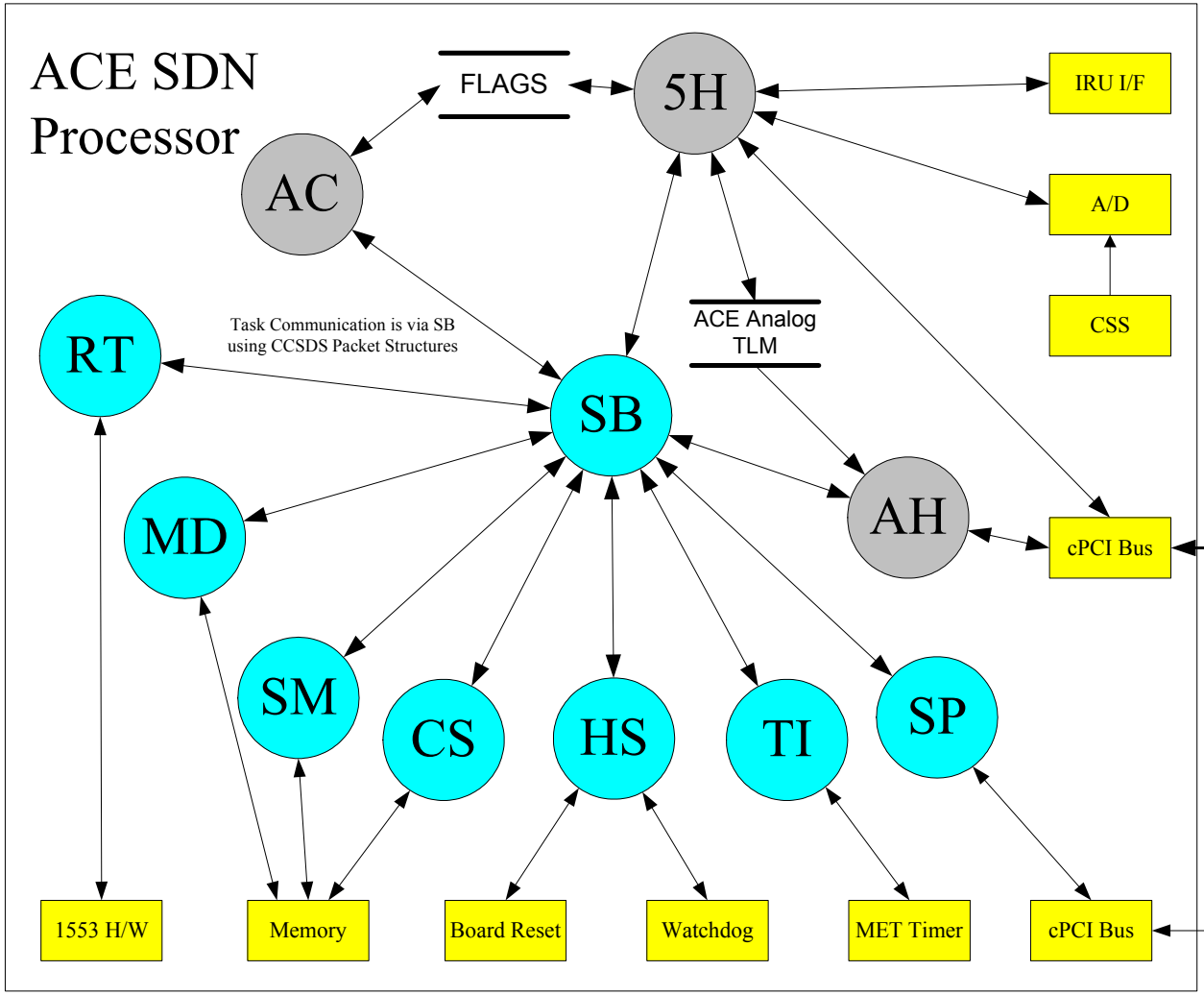
PSE SDN FSW Architecture



SB-Software Bus
HS-Health & Safety
CS-Checksum
SM-Software Manager
TI-Time Code
RT-1553 Remote Terminal
SP- Switch Card
MD - Memory Dwell

BC- Battery Charging Control
MT- Monitor
CT- Command Control

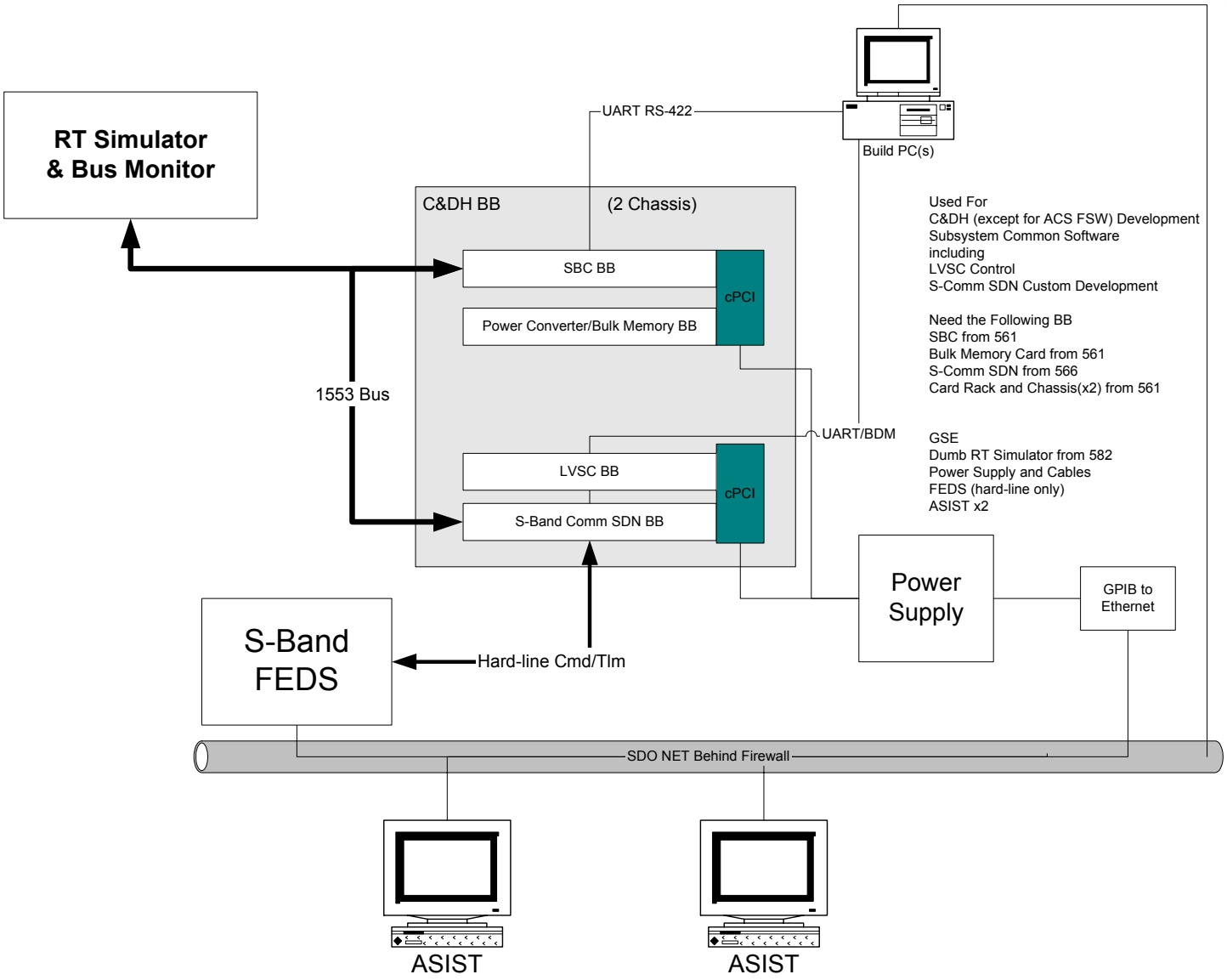
ACE SDN FSW Architecture



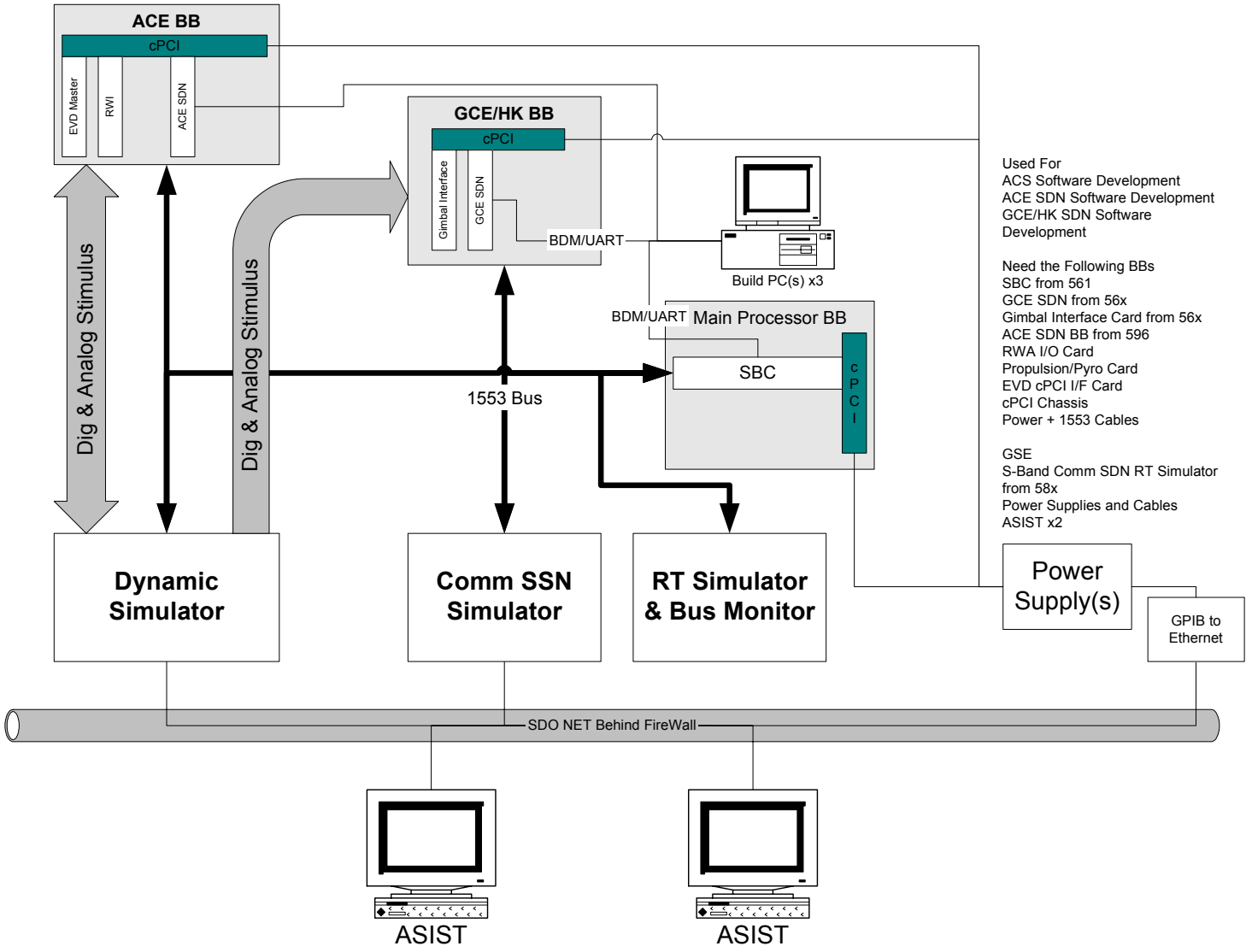
SB-Software Bus
HS-Health & Safety
CS-Checksum
SM-Software Manager
TI-Time Code
RT-1553 Remote Terminal
SP- Switch Card
MD - Memory Dwell

AC - 1 Hz Command Task
5H - 5 Hz Task, SAFEHOLD, Actuator Commands, Sensor Data Reading
AH - Analog Housekeeping

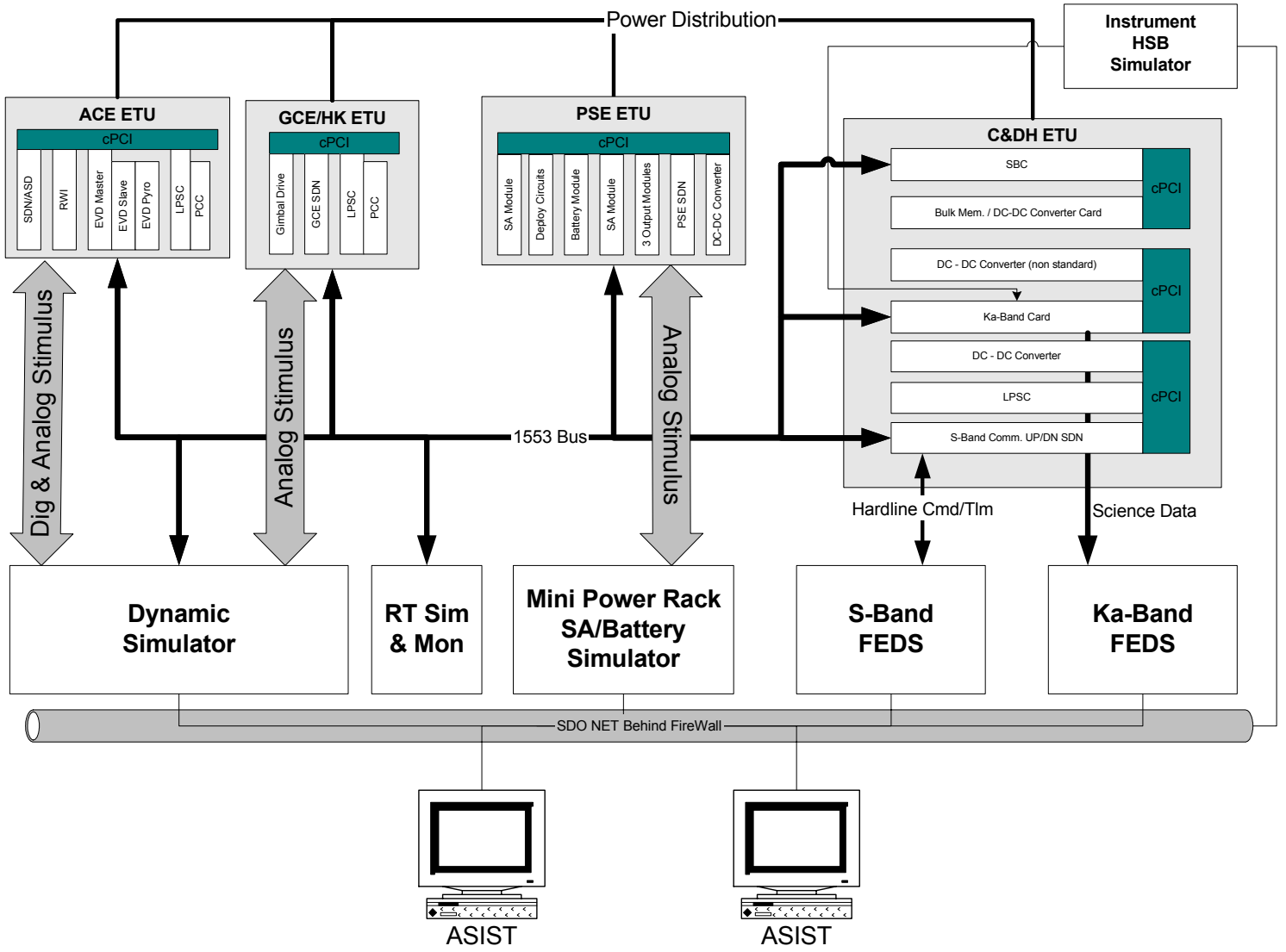
C&DH FSW Development String



ACS/ACE/GCE FSW Development String



SDO FLATSAT


Power Distribution
Instrument HSB Simulator
ACE ETU
cPCI
SDN/ASD
RWI
EVD Master
EVD Slave
EVD Pyro
LPSC
PCC
GCE/HK ETU
cPCI
Gimbal Drive
GCE SDN
LPSC
PCC
PSE ETU
cPCI
SA Module
Deploy Circuits
Battery Module
SA Module
3 Output Modules
PSE SDN
DC-DC Converter
C&DH ETU
SBC
Bulk Mem. / DC-DC Converter Card
cPCI
DC - DC Converter (non standard)
Ka-Band Card
cPCI
DC - DC Converter
LPSC
S-Band Comm. UP/DN SDN
cPCI
Dig & Analog Stimulus
Analog Stimulus
1553 Bus
Analog Stimulus
Hardline Cmd/Tlm
Science Data
Dynamic Simulator
RT Sim & Mon
Mini Power Rack SA/Battery Simulator
S-Band FEDS
Ka-Band FEDS
SDO NET Behind FireWall
ASIST
ASIST